MINERAL FERTILIZER USE EFFICIENCY IN SPRING BARLEY SOWINGS

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ABSTRACT. *Optimum rates of the nitrogen (N) fertilizer in spring barley Tocada sowings were studied in field trials established at the Research and Study Farm „Pēterlauki" of the Latvia University of Agriculture (LLU) over the period 2008–2010. Field trials were conducted on a silt loam brown lessive soil (sod calcareous) with medium high phosphorus (P) and potassium (K) sufficiency levels. Fertilizer treatments: $N_0P_0K_0$ – control (unfertilized); PK fertilizer was equal in all N treatments: N_0, N_{30}, N_{60}, N_{90}, N_{120}, N_{150}, N_{180}, N_{210}.*

Plant nutrient removal with yield is dependent on crop yield level and nutrient content in basic products (grain) and by-products (straw). Nitrogen removal is associated with yield increase as affected by N fertilizer and with the increase of N content in grain and straw. N removal with yield within treatments studied increased from 80 to 145 kg ha^{-1}. The increase in P_2O_5 removal with yield between minimum and maximum value was only 15 kg ha^{-1} and was associated almost only with the increase in grain yield. Difference between minimum and maximum value of K_2O removed was more than two times greater – from 45.5 to 98.1 kg ha^{-1}.

Utilization coefficients of plant nutrients are, to a great extent, dependent on meteorological situation in the growing season. On the average for three years, mineral N utilization coefficient was the highest with nitrogen fertilizer rate N_{60} – 0.44, retaining constant relationship that utilization coefficient gradually decreases with each succeeding N fertilizer rate.

Utilization indices of P_2O_5, averaged over 3 years, are comparatively small however the increase in N fertilizer rate resulted in the increase of P_2O_5 removal. Similar tendencies were observed when analyzing potassium utilization coefficients.

Calculating optimum fertilizer rates, predicted crop yield level and peculiarities of meteorological situation in specific year should be taken into account when quantifying additional fertilizer rates.

Keywords: *spring barley, N uptake, Nitrogen use efficiency.*

Introduction

The crop yield level and quality in today's production agriculture are greatly dependent on utilization and application of mineral fertilizers. Mineral nitrogen combined with appropriate supply of other plant nutrients is one of the most important and effective fertilizers for high yield production. In the whole world about a 100 million ton of mineral nitrogen is used yearly however, unfortunately, not all amounts are utilized by plants for yield formation. A great part of it is migrating into ground waters, rivers, or otherwise and is a hazard to environmental pollution (Glass, 2003).

In compliance with EU Council Directive 91/676/EEC of 12 December 1991 with regard to water protection against pollution caused by residual nitrate of agricultural origin, excessive fertilizer use endangers environment and therefore measures are needed to limit incorporation of all N-containing fertilizers into soil.

With regard to the Opinion of the European Commission on Nitrate Directive implementation in Latvia in the period 2004–2008, maximum mineral fertilizer rates applied for different crops and limitations in mineral fertilizer use shall be laid down based on research results and conclusions.

Based on 'Latvian Rural Development Program 2007−2015', a document developed for agricultural policy making and on the aims defined there, maximum permissible rates for mineral fertilizer application, and those for mineral N in particular, are to be determined and observed.

In recent years, the increase in crop yield level in farms is reached through more intensive field crop varieties considerably higher in yield potential compare to those used in the 1980's or even 90's. For crop varieties of such a type, utilization of their genetic yielding potential without strict observation of all other cultural operations requires also comparatively high nutrient supply. Under production concentration and specialization, mineral fertilizer is the main source of plant nutrient supply in most of farms now. Wherewith, amounts of applied mineral fertilizers, and mainly mineral N amount applied per unit area, like in other countries, continue to increase particularly in economically strong large-scale farms (Angas *et al*., 2006; Ruza *et al*., 2010).

Indices for particular plant nutrient utilization in Latvia were determined in the second half of the last century under different production conditions. Researches on mineral fertilizer utilization and mineral N in particular have not been conducted under new conditions of production. Recent plant nutrient investigations were associated more with crop yield increase and quality improvement in particular.

Nitrogen is a most dynamic plant nutrient which uncontrolled application at the current cost level may considerably raise the price of end-product, and what is more important – increased rates of N insufficiently utilized by plants may result in environmental pollution (Moreno *et al*., 2003; Macdonald A. J. *et al*., 2009). The topic of the day is what maximum N fertilizer rates are profitable under Latvian soil and agro climatic conditions and what is allowable level to which increase amount of applied nitrogen fertilizer preventing harm to the environment.

Materials and methods

Optimum rates of the nitrogen (N) fertilizer in spring barley Tocada sowings were studied in field trials established at the Research and Study Farm „Pēterlauki" of the Latvia University of Agriculture (LLU) over the period 2008-2010. Field trials were conducted in four replications on a silt loam brown lessive soil (sod calcareous) with medium high phosphorus (P) and potassium (K) sufficiency levels. Fertilizer treatments: $N_0P_0K_0$ – control (unfertilized); N_0PK – PK fertilizer was determined at nutrient removal up to 6 t ha^{-1} grain and in succeeding N treatments: $N_{0,}$ N_{30}, N_{60}, N_{90}, N_{120}, N_{150}, N_{180}, N_{210} PK fertilizer was equal. P_2O_5, K_2O and the first mineral N fertilizer rate till norm N90 was pre-plant incorporated during pre-sowing tillage. During growing season all the necessary plant protection measures were performed.

Up-take of N, K_2O and P_2O_5 were noted and coefficient of mineral fertilisation utilization was calculated. Standard deviation and coefficient of determination (R^2) were calculated by Excel MS tools.

The growing season in 2008 after barley sowing in the third decade of April was dry. Dry conditions almost without rainfall prevailed all the month of May – in the second decade 8.2 mm rainfall received in several days was only poor dew on the arid soil. Dry weather continued all the first decade of June. Barley plants tillered poor, and further growth of plants was non-uniform. Precipitation in the second and third decades in June noticeably improved general status of barley plants, sowing became uniform by plant height and formed comparatively productive spikes. In general, the long-lasting period of dryness in spring significantly influenced growth and development of plants and yield formation process.

Spring in 2009 was comparatively warm, windy and dry – in the second and third decades of April rainfall was not observed at all. In May as well only 35% long-term rainfall sum was recorded. Such weather conditions resulted in non-uniform seed germination and non-uniform initial growth. However the first half of June was somewhat cooler with adequate rainfall providing good conditions for plant growth and development. Successive period of time was also favourable for spring barley yield formation.

In 2010 spring barley germinated very uniformly and favourable meteorological conditions in the first half of the growing season contributed to growth and development. However the following period of time was hot and non-characteristic to Latvia. In July and early August, the average air temperatures in decades were 3−6^{0}C higher than the long-term averages and they were exceedingly rich in rainfall − twice as much as the long-term averages. Abundant rainfall combined with strong wind resulted in completely lodged barley stands causing difficulties at harvest.

Results and Discussion

Grain yields obtained in 2008 indicate that trial soils without fertilizer application and meteorological situation in this specific year provided comparatively high mean grain yield – 4.17 t ha^{-1}. Application of phosphorus and potassium fertilizer did not give yield increase – deviation is stated within error. In this case nitrogen was, obviously, the limiting factor. Incorporation of N30 per hectare gave 26.7 % yield increase. Yield level remained equal also with fertilizer N60. The increase in nitrogen fertilizer rate up to N90 still gave grain yield 10% more or 35.4% against initial indice. Further increase in N rate practically did not influence the yield level of barley grain, fluctuations were within error. Under the influence of N fertilizer the ratio of grain to straw did not change and was within 1:1.0–1.1.

In comparatively dry spring in 2009, the obtained grain yield in N-free treatments was only 1.84 t ha^{-1}. However already nitrogen fertilizer rate N30 resulted in grain yield increase 1.30 t ha^{-1}. Each succeeding nitrogen fertilizer step up to N90 resulted in significant yield increase. Further increase in N fertilizer rates resulted in somewhat higher grain yield reaching the highest value 4.92 t ha^{-1} in treatment N210.

In general, in 2010 grain yields of spring barley were comparatively good. Such meteorological conditions intensified nitrification process in soil and nitrogen practically did not influence the yield of grain – irrespective of fertilizer rate, grain yields with small fluctuations were equal in all treatments with a tendency to decrease at higher N rates (N90 + 60 and N90 + 90). The ratio of grain to straw, assuming that grain weight is 1, was 1: 0.76 on average. As the nitrogen fertilizer did not contribute to significant yield increase, wherwith incorporated nitrogen utilization indices under conditions of that year were exceedingly low – within 10–25%. Also phosphorus and potassium utilization from the incorporated fertilizer were comparatively very low.

The three-year averages were significantly influenced by non-characteristic meteorological conditions in 2010 when grain yields up to 6.75 t ha^{-1} were obtained in N-free fertilizer treatments on P_2O_5 and K_2O backgrounds. However the three-year averages (Figure 1) suggest that the increase in barley grain yield under Latvian conditions is comparativily stable with applied nitrogen fertilizer rate up to N90. Results of research conducted in other countries show that, depending on climatic zone and soil peculiarities, the highest spring barley yields are obtained with fertilizer rates N 60–120 kg ha^{-1} (Delogu *et al*., 1998; Kaš *et al*., 2010). Research results obtained both by our researchers and those in other countries indicate that further influence of nitrogen fertilizer rate on yield level is more dependent on the character of the growing season (Moreno *et al*., 2003). Wherwith, application of the first mineral N fertilizer rate not exceeding N90 kg ha^{-1} is useful. Further necessity for nitrogen must be determined depending on the character of the growing season and plant status.

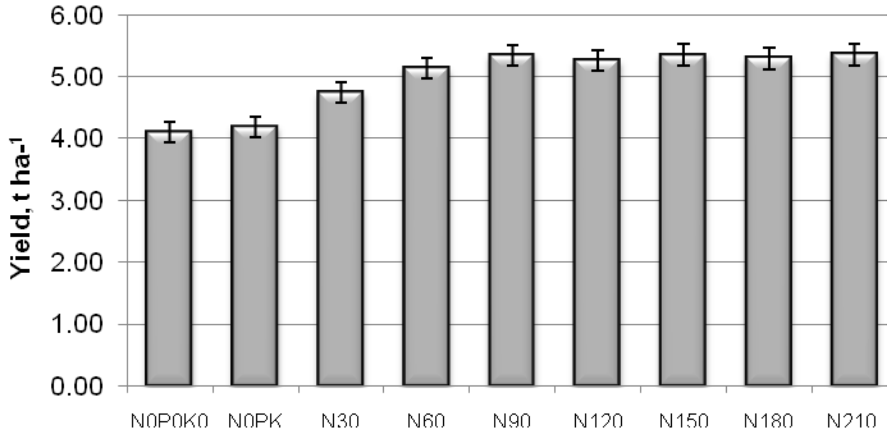

Figure 1. Grain yield, on the three-year average, t ha^{-1}

Nitrogen use efficiency or amount of grain obtained per unit of utilized nitrogen fertilizer is one of the most important indices (Brauer, Barry, 2010). Information summarized in Figure 2 suggest that the highest return from the nitrogen fertilizer − 18.2 kg grain per 1 kg N applied – was obtained with the lowest nitrogen fertilizer rate – N30. Each succeeding nitrogen fertilizer rate applied resulted in gradual decline in N use efficiency reaching 70% between the lowest and the highest nitrogen fertilizer rate. Similar results have been reported in Italy (Delogu, 1998), Spain (Angas, 2006), and in the Czech Republic (Kaš, 2010), that the increase in N ferilizer rate results in the decrease of its use efficiency. The highest reduction in obtained amount of grain per 1 unit N applied was stated for nitrogen fertilizer rates between N90 and N120. Results of data processing also suggest that the nitrogen use efficiency is exactly dependent on the nitrogen fertilizer rate – $R^2 = 0.9826$.

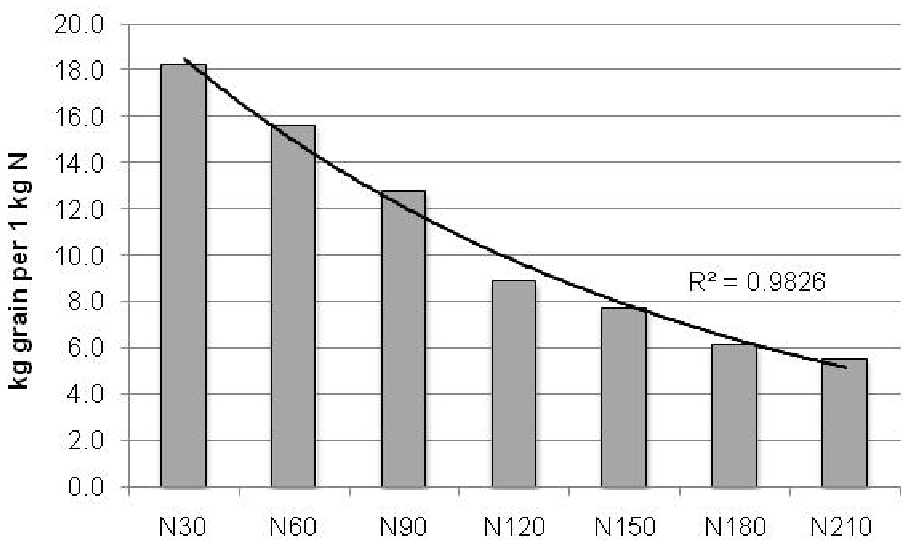

Figure 2. Grain amount obtained per 1 kg N applied

Amount of grain obtained per 1 unit N applied taken as a basis, it is simply to calculate the fertilizer rate at which further increase is unprofitable.

Macronutrient content in grain and straw also changed considerably depending on N fertilizer rate applied. The three-year averages indicate that the increase in N fertilizer rate resulted in gradual increase in grain nitrogen content from 1.52% in N-free treatment to 2.03% with fertilizer rate N180 (Table). Nitrogen content in straw at the same time increased almost twice in these treatments – from 0.44% to 0.85%. P_2O_5 content in grain was not practically influenced by the increased N rates, in straw as well the increase in P_2O_5 content was insignificant – only 0.05%. K_2O content in grain was not influenced by the increase in N fertilizer rates. However K_2O content in straw with the increase in N fertilizer rate increased constantly (more than twice) – from 0.65% in control treatment to 1.57–1.45% in treatments N150, N180.

Table 1. N, P_2O_5 and K_2O content in grain and straw, on the three-year average, %

Treatment	N		P_2O_5		K_2O	
	grain	straw	grain	straw	grain	gtraw
$N_0P_0K_0$	1.52	0.44	0.61	0.19	0.51	0.65
N_0PK	1.56	0.51	0.64	0.22	0.50	0.99
N_{30}	1.70	0.53	0.63	0.21	0.53	0.92
N_{60}	1.85	0.60	0.68	0.20	0.52	1.12
N_{90}	1.84	0.66	0.65	0.22	0.53	1.20
N_{120}	1.99	0.76	0.66	0.22	0.52	1.21
N_{150}	1.90	0.85	0.66	0.24	0.52	1.57
N_{180}	2.03	0.85	0.69	0.23	0.52	1.45
N_{210}	2.00	0.83	0.67	0.24	0.50	1.25

Plant nutrient removal with yield is dependent on crop yield level and nutrient content in basic products (grain) and by-products (straw). Nitrogen removal is associated with yield increase under the influence of N fertilizer and with the increase of N content in grain and straw. However exceeding fertilizer rates N 90−120 kg ha^{-1}, the increase in nitrogen removal is due to increase of N content in grain and straw. Wherewith, nitrogen removal with yield within investigated treatments increased from 80 to 145 kg ha^{-1} (Figure 3). The increase in P_2O_5 removal with yield between minimum and maximum value was only 15 kg ha^{-1} and was associated almost only with the increase in grain yield. At the same time K_2O removal with yield was two times greater as it was indicated by difference in minimum and maximum value – from 45.5 to 98.1 kg ha^{-1} or about 60% utilized nitrogen amount. Literature findings give evidence that total amount of K_2O taken up by plants is exceeding that of total nitrogen but it was not evident in our studies. Adequate amount of potassium also increases the nitrogen use efficiency (Johnston, 2009).

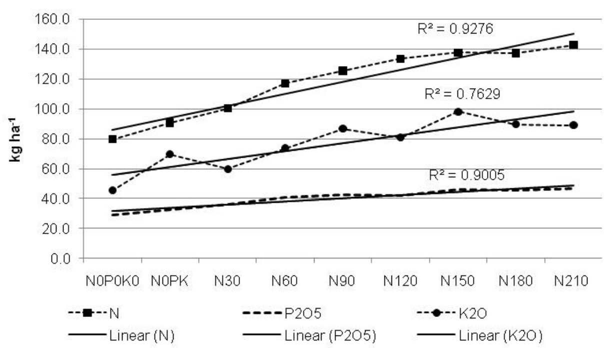

Figure 3. N, P_2O_5, K_2O removal with yield, on the three-year average, kg ha^{-1}

Plant nutrient utilization coefficients or agronomic efficiency was greatly dependent on meteorological situation in the growing season and therefore greatly differed between years. In these studies considerable dissonance was caused by uncharacteristic meteorological situation in 2010 when extremely abundant rainfall and increased air temperatures intensively favoured soil biological processes and nitrification in particular.

Mineral nitrogen utilization coefficients were the highest in 2009 – from 0.66 to 0.35 with definite coherence that the increase in nitrogen fertilizer rate resulted in the decrease of its agronomic efficiency. Similar coherence, but only with somewhat lower indices, was stated also in 2008 – coefficients from 0.61 to 0.28. However in 2010, the nitrogen utilization coefficients were comparatively very low without definite coherence that influenced the three-year averages significantly (Figure 4). On the average for the three trial years, the highest mineral N utilization coefficient was stated for the nitrogen fertilizer rate N60 – 0.44, retaining coherence that with each successive N fertilizer rate the value of utilization coefficient decreases.

P_2O_5 utilization coefficient with the increase in N fertilizer rate in 2008 and 2009 persistently increased. However the highest values were stated in 2009, reaching 0.52 in treatments N180-210. Similar coherence was stated also in 2008 but only with somewhat lower values. However in 2010, like with N fertilizer, P_2O_5 utilization coefficients were exceedingly low and without definite coherence. Wherewith, the three-year average P_2O_5 utilization coefficients were comparatively low however retained coherence that with the increse in N fertilizer rates P_2O_5 utilization coefficient increased.

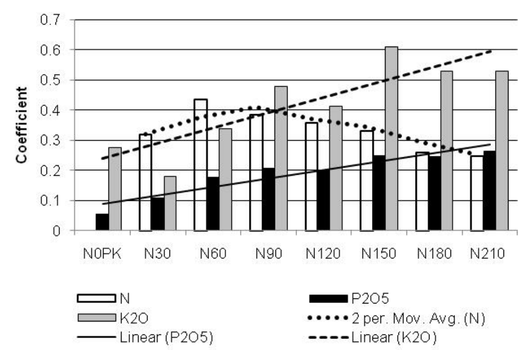

Figure 4. N, P_2O_5, K_2O utilization coefficients

The increase in N fertilizer rate in 2008 and 2009 considerably increased K_2O utilization coefficient – from 0.18 to 0.78 in 2008, but in 2009 from 0.24 to 0.69. In 2010, also potassium utilization coefficient from the mineral fertilizer, like that of N and P_2O_5, was very inconstant between particular treatments without definite coherence that significantly influenced the three-year averages. Wherewith, K_2O utilization coefficients between separate treatments considerably decreased, however like P_2O_5 utilization, general coherence retained that with the increase in N fertilizer rate K_2O utilization coefficient from mineral fertilizer also increased on yield increase and, particularly, on the increase in straw potassium content. Other authors have also reported that potassium utilization efficiency increases with the increase in nitrogen rate. Excess of optimun potassium and nitrogen rates did not give further yield increase. Rate, timing and form of nitrogen application influence potassium fixation, N uptake and transporting in plants. K application could reduce N leaching because increases its uptake (Zhang *et. al.*, 2010).

Conclusions

Plant nutrient removal with yield is dependent on yield level and nutrient status in basic product (grain) and by-product (straw). Nitrogen removal is associated with yield increase under the influence of nitrogen fertilizer and with the increase in nitrogen content in grain and straw. Nitrogen removal with yield within investigated treatments increased from 80 to 145 kg ha^{-1}. The increase in P_2O_5 removal with yield between minimum and maximum value is only 15 kg ha^{-1} and is associated almost only with grain yield increase. The difference between minimum and maximum value in K_2O removal is more than twice greater – from 45.5 to 98.1 kg ha^{-1} or about 60% from the nitrogen removed.

Agronomic efficiency of plant nutrients is greatly dependent on meteorological situation in the growing season. On the average for three years, the highest mineral nitrogen utilization coefficient is stated for the nitrogen fertilizer rate N60 – 0.44, retaining coherence that with each successive nitrogen fertilizer rate utilization coefficient gradually decreases.

Increasing nitrogen fertilizer rate P_2O_5 removal increases. Similar coherence is stated also for potassium utilization indices.

Calculating fertilizer rates, P_2O_5 and K_2O amounts are determined according to predicted yield level considering their utilization coefficient at the corresponding yield level. Nitrogen fertilizer rate up to N90 must be pre-plant incorporated, the need for top-dressing must be considered taking into account peculiarities of meteorological situation in specific year.

Acknowledgement

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